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Southern Research Inst, Birmingham, AL

Prepared for

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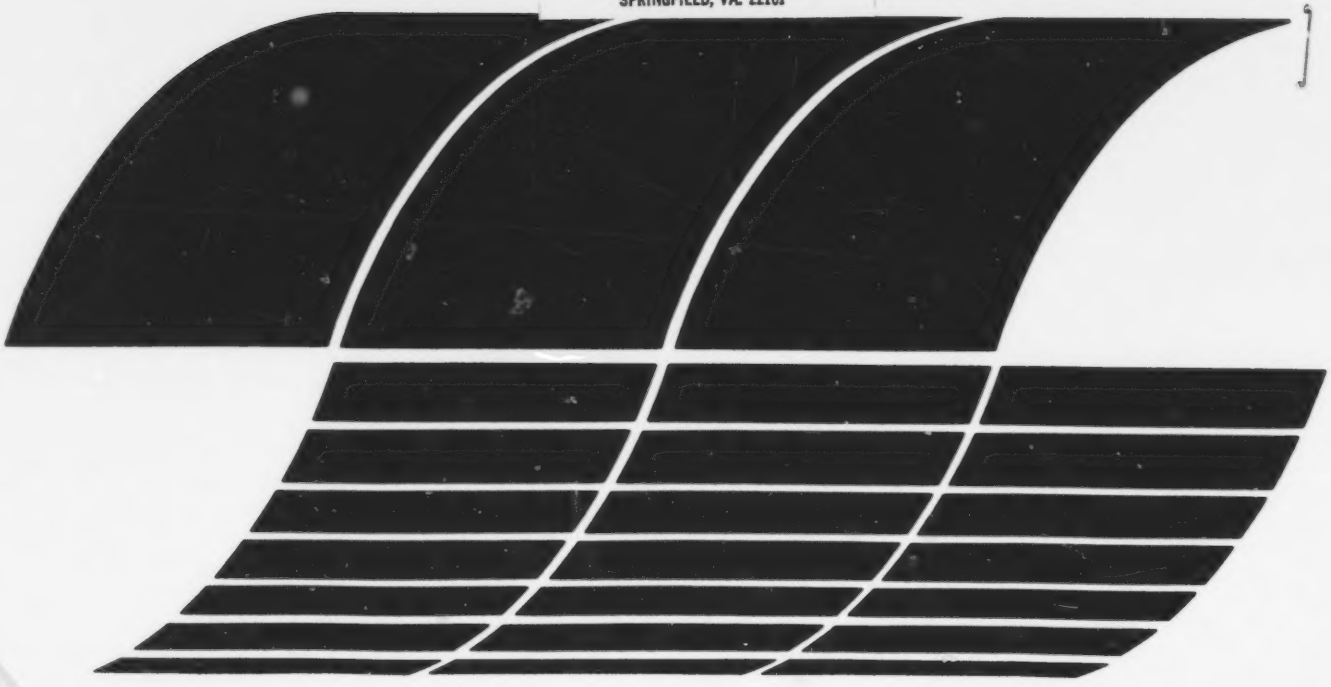

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Electrostatic Precipitator Technology Assessment: Visits in Japan, November 1977

by

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Contract No. 68-02-2610
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EPA Project Officer: James H. Abbott

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ABSTRACT

This report describes the results of a particulate control technology assessment visit to Japan by a team of United States Investigators. The visit included discussions with personnel from universities, industries and major installations involved with particulate control. Significant research activities were noted in both the academic and industrial sectors related to particulate control and measurements.

The report summarizes these results of the individual discussions, observations during these tours, and discussions of technical papers. Many valuable technical papers were supplied to the U.S. Team. These papers are reproduced in the Appendix of this report, EPA-600/7-78-110a.

EXECUTIVE SUMMARY

This report describes the results of visits and consultations with research facilities in universities and industrial installations as well as inspection trips to operating plants. The visit was planned with the assistance of Dr. Jumpei Ando of Chuo University in Tokyo and Mr. Kiyoshi Suito of Japan Management Association.

The visit with Professor Senichi Masuda of Tokyo University provided information about their research activities into the fundamental factors that cause the development of the disruptive condition termed "back corona" that is related to current flow through a high resistivity dust layer in operating electrostatic precipitators.

We also discussed their research into the use of pulse energization with a three-electrode system used in conjunction with a high electric field-low current density collector. This combination of technology leads to reasonably effective collection of high resistivity particulate.

Another interesting area of research at Tokyo University involves studies of the influence of "electric wind" related to the directed motion of ions under the influence of the electric field as well as studies of enhanced scrubbing of gases when the ionic wind related turbulences and electrical activity are present. There is currently some disagreement between researchers as to the influence of electric wind in electrostatic precipitation. The general consensus of United States, Russian, and European researchers is that the effect of electric wind is negligible for electrical current densities normally encountered in industrial applications.

Several research groups in Japan are involved in research to determine the optimum corona to collection electrode spacing in electrostatic precipitators. In general, wider plate spacings provide a greater collection efficiency per area of collection electrode for low mass loading situations. Increases in plate spacings, coupled with higher operating voltages lead to increased collection rates so long as the average current density can be maintained in the control device. These wide plate spacings promise two significant advantages, so long as the collection efficiency can be maintained. First, the cost of a given installation will be reduced since smaller quantities of steel will be required and, second, the weight of the control device will be less which will result in a reduced load on the structure for roof mounted installations.

An area of research that is related to particulate control involves measurements of particulate characteristics. Professor Yoshida of the Osaka University has an extensive research program in this area. This group has developed an instrument—an ultramicroscope—that is useful for studying the behavior of particles suspended in a gas stream. The device consists of a microscope coupled to a television display system that is used for viewing particles at a given distance inside a gas stream. This instrument is used to study several aspects of particulate behavior: growth of particle by condensation, stability of droplets in a cloud or fog, Brownian diffusion and coagulation, and particle size analysis.

The Hitachi group has developed an optical particle counting system that includes a gas dilution system that is useful for determining particle size distribution for a range of particle sizes up to about 100 μm diameter. The dilution system is stated to yield a constant dilution for all particle sizes up to this 100 μm range.

Some studies of SO_x and NO_x removal in electrically active regions are reported. In one case an electron beam (1-2 Mev electrons) is directed into the gas stream while in another a high current density corona system provides the ozone necessary to enhance the oxidation of the gases to reactive states.

In general, the research activities in Japan are on a par with the United States, Europe and the Soviet Union. In some instances, particularly pulse energization, electrode spacing and, perhaps, fundamental studies of back corona, they are ahead of others. The research efforts should be monitored and information exchanged on a routine basis for the mutual benefit of both the United States and Japan.

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SECTION I

SUMMARY

This report includes the results of discussions and technical publications from a variety of research and industrial concerns in Japan that are related to particulate control. The visits reported are with the University of Tokyo relative to research into the electrostatic collection of particulate. The significant work with back corona formation and pulse energization is reviewed. The visit to Ishikawajima-Harima Heavy Industries provided information about a commercial application of a specialized application of the pulsed energization technique from Tokyo University.

The Hitachi discussions provided information about some industrial research with high electric field-low current collectors, wider than normal plate spacings and optical particle sizing instrument development.

The Sumitomo group is a licensee of the U.S. company - Joy-Western. They also conduct research into variations in plate spacings. They described the use of pilot scale electrostatic precipitators in the sizing of new installations.

The visit to Nippon Steel-Kimitsu Works provided an opportunity to observe the pollution control techniques in one of the significant Japanese industries. One of the wide plate spacing electrostatic precipitators was operating successfully at this site.

The Shinwa Trading Company enjoys a monopoly in the particulate control from coke ovens, ferrosilicate arc furnaces and fugitive emissions from the iron and steel works in Japan. They are a licensee of American Air Filter. They have developed a traveling collection system for use in controlling the emissions from coke oven pushings.

The Isogo Power Station is equipped with Lodge-Cottrell and Sumitomo electrostatic precipitators. An SO_3 injection system is provided for resistivity modification. This station also has Chemico slurry limestone scrubbers for SO_x control.

The visit with Kyoto University provided an opportunity to discuss some aspects of fabric filter particulate control research. Papers covering a wide range of topics were provided.

The Osaka University research group has developed an instrument for directly viewing the behavior of particles suspended in a gas. Many experiments were discussed that were very pertinent to particulate studies. The instrument is termed an ultramicroscope.

The Mitsubishi Research Laboratories gave the research team an opportunity to closely evalute a significant industrial research laboratory. This laboratory is equipped with pilot-scale electrostatic precipitators and a wide variety of related instruments. They are a licensee of Lurgi in Germany.

The results of these discussions and studies led the U.S. Team to the conclusion that the level of electrostatic precipitator technology in Japan was on a par with and in some instances superior to research activities in the United States, Europe and the Soviet Union. The two areas where the Japanese technology was deemed to be superior was in the area of pulse energization for electrostatic precipitators and in the fundamental studies of back coronas.

SECTION II

INTRODUCTION

A research team representing the United States Environmental Protection Agency visited a number of academic and industrial research facilities in Japan to assess the level of electrostatic precipitator technology in Japan. These information transfer meetings were arranged through the Japan Management Association working in conjunction with Professor Jumpei Ando of Chuo University in Japan. Japan Management Association provided interpreters and other valuable assistance during the period of this visit. Mr. Kiyoshi Suito of J.M.A. was responsible for this service.

The visits to each installation consisted of discussions between the U.S. and Japanese members; tours and demonstrations in the research and industrial facilities; and an exchange of information between the participants.

The research team consisted of Mr. James H. Abbott, Chief, Particulate Technology Branch, Industrial Environmental Research Laboratory, United States Environmental Protection Agency, Research Triangle Park, NC; Dr. Leslie E. Sparks, Chemical Engineer, Particulate Technology Branch, Industrial Environmental Research Laboratory, United States Environmental Protection Agency, Research Triangle Park, NC; and Mr. Grady B. Nichols, Associate Director, Engineering and Applied Sciences, Southern Research Institute, Birmingham, Alabama.

SECTION III

PURPOSE

The principal purpose of this visit was to assess the state of technology of electrostatic precipitators, both from a research and applications point of view. In addition, the state of technology of alternative particulate control devices was reviewed when appropriate.

Considerable research has been conducted on particulate control devices in Japan. Some of the work has been reported in international journals, while much was only available in Japan proper. In many cases, discussions of techniques and alternative interpretations are important. In addition, data presented in international journals are at least one year old. Therefore, personal contacts with an interchange of ideas are often required. These discussions aided immeasurably in assessing the state of particulate control technology in Japan.

In each visit the leader of the U.S. Team opened the meeting by reviewing the purpose of the visit. The primary purpose was to assess the state of technology for electrostatic precipitators in Japan. The significance of the meaningful research and industrial applications of electrostatic precipitator technology and how this technology could be used to advantage by the U.S. was stressed.

The following technical publications from the U.S. Environmental Protection Agency were provided as exchange information to the Japanese research team:

- Impact of Switching to Low Sulfur Coal on Particulate Emissions
- Control of Fine Particulate Emissions - E.P.A. Program Description
- Hand Calculator Program Descriptions - HP25 and HP65
- Electrostatic Capture of Fine Particles in Fiber Beds
- High Temperature - High Pressure Particulate Control Requirements

- Fine Particle Charging Development

- Venturi Scrubber Performance Model

- A Mathematical Model of E.S.P. Performance

- Proceedings - Particulate Collection Problems Using ESP's in Metallurgical Industry

- Procedures Manual for E.S.P. Evaluation

SECTION IV

ASSESSMENT DISCUSSIONS

The technology assessments consisted of discussions between the U.S. team and research groups from both universities and industrial concerns. Several areas of significant research were noted. Two specific examples include studies of the results of varying the plate to corona electrode spacing and the investigation of the influence of adding devices designed to increase the collecting electric fields in a limited region immediately downstream from the conventional electrostatic precipitator.

Another area of research that is related to particulate control is involved with the development of instrumentation to measure particulate physical characteristics. These research topics were also included in the discussion.

Each visit is reviewed in this section including a summary of the discussions and a list of the information exchanged. Copies of the technical literature received at each meeting are included as appendices to this report (in EPA-600/7-78-110a).

UNIVERSITY OF TOKYO
Professor Senichi Masuda
Department of Electrical Engineering

Professor Masuda reviewed the current and recently completed research programs within his department that were related to electrostatic precipitation. He provided copies of technical presentations that resulted from this research. The principal conclusions from the research is included in the discussion review.

Back Corona Initiation

The electrical breakdown within a layer of material is related to the electric field that exists within the material. For materials where Ohm's Law applies, the electric field is proportional to both the current density and resistivity of the material ($E=j\rho$). This applies when a single stage electrostatic precipitator operates with a given corona current density (j) and with a previously collected dust layer with a given resistivity and thickness (ρ,t). For these cases when the electrical

resistivity is high ($\rho > 10^{11}$ ohm-cm), the electric field within the dust layer is greater than that in the gas stream immediately adjacent to the layer. This step function in the electric field is caused by a surface charge layer on the dust (σ) proportional to the dielectric constant ($\sigma = \varepsilon \Delta E$). This surface charge reaches a steady state value such that the current density in the layer is equal to the current density in the space adjacent to the layer (current continuity).

The above considerations led to the design of some simplified laboratory experiments where the ash layers were represented by millimeter thick layers of glass. The glass layers have pinholes that extend through the glass layers. Changes in the normal and tangential electric fields are simulated by displacing these holes using two sheets of glass. The U.S. team suggested that the surface charge layer on the mating glass surfaces and the air space between may upset the idealized conditions. Several conclusions from these experiments are as follows:

- Obtain no flashovers if E field low adjacent to collection electrode (less than 5 kv/cm for this experimental condition - related to mean free path).

- Without flashovers - small streamers develop and quench repetitively.

- Two phenomena occur - streamer (bright) followed by diffuse glow (low intensity) - must view with image intensifier.

- With E between 5 and 8 kv/cm channel streamers develop into flashover - no back discharge.

- If E>8 kv/cm flashover similar to those with no dust layer.

Painting the glass surface with a thin layer of potassium salt causes the flashover phenomena to change. Masuda postulated that the emission of potassium atoms into gas stream influences flashover (possibly surface resistivity is a more likely explanation since extremely trace quantities of K atoms would result). He also states that presence of NO_2, CL_2 or SO_2 influences flashover. Professor Masuda believes that increasing current, when diffuse glow (back corona) is present, leads to increased performance in electrostatic precipitator. For the high resistivity case, he expects $0.1 \mu A/cm^2$ is a good current density. (This is well below any operating electrostatic precipitator.) Again note - a very high resistivity material was used.

Dr. Masuda has studied the electrical upset phenomena associated with current flow through a high resistivity dust layer. He identified three classes of electrical upsets. The classes

of upset observed parallel the observations of U.S. investigators. These classes are:

Electrical arc preceded by spark
Distributed glow discharge leading to spark
Glow discharge increasing to arc

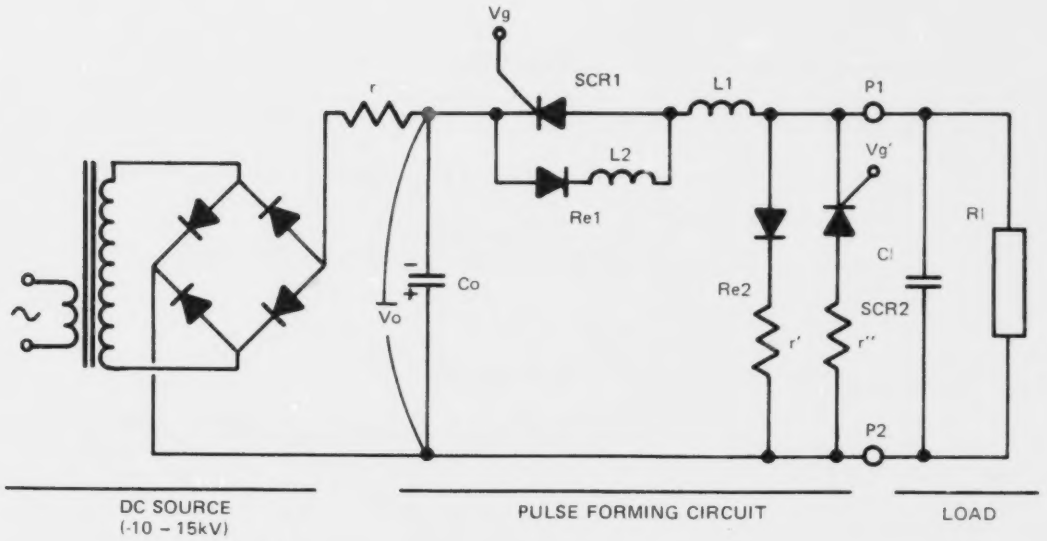
These regions of operation are identified in graphs in his paper, "Flashover Measurements of Back Discharge for Extremely High Resistivity Dusts". See Section V-1 and Appendix A.

Several investigators in various parts of the world have studied the application of pulse energization for electrostatic precipitators. In general, the voltage on the collection electrode could be increased as a step function but the time constant associated with the distributed capacitance of the electrode system and the dust layer coupled with the dynamic resistance of the same system causes the decay of voltage to follow a characteristic with approximately 20 millisecond time constant.

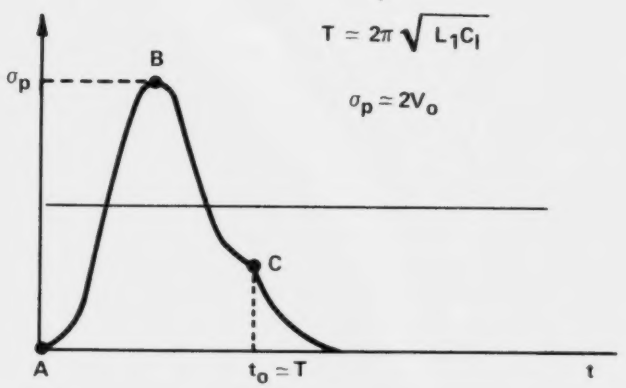
Dr. Masuda has added an inductance to this system that leads to an electrical resonance where sharp rise and fall times are provided. Thus, a pulse can be added to a D.C. background voltage that may lead to improved performance in some instances. This system provides ∿150 microsecond pulses to a standard electrostatic precipitator system. The following figure illustrates the technique by which this is accomplished.

Professor Masuda gave us copies of the following papers included as Appendix **A.**

- Initiation Condition and Mode of Back Discharge
- Back Discharge Phenomena in A Bias Controlled Pulse Charging System
- Light Measurement of Back Discharge
- Initiation Condition and Mode of Back Discharge for Extremely High Resistivity Powders
- Utility Limit and Mode of Back Discharge in Bias-Controlled Pulse Charging System
- The Analysis of Electric Wind in Electrostatic Precipitator by Laser Doppler Velocimeter
- Fundamental Analysis of Electron Beam Gas Elimination
- Motion of a Microcharge Particle Within Electrohydrodynamic Field



CI: load capacity including cable and stray capacities,
RI: load resistance corresponding to corona discharge,
Co: main capacitor (≃10 CI)
L1: coil inductance for L-C oscillation
SCR1: switching element triggered by input signal v_g,
L2: protective coil,
Re1: fly-wheel rectifier
SCR2: dwitching element for draing off the residual charge
Remark: By triggering the SCR the load condenser is charged up to a peak value = 2 Vo by transient L-C oscillation through Co-SCR-L1-CI. Then, the discharging oscillation occurs through CI-L1-L2-Re1-Co. The following wave form of output pulse voltage can be obtained. The pulse width is determined by the oscillation period given by:



At time t_o, SCR2 is triggered. The pulse width of 150 - 500 microseconds are obtained.

- A Preliminary Study of Reentrainment in an Electrostatic Precipitator

- Recent Progress in Electrostatic Precipitation

- Flashover Measurement of Back Discharge

- Basic Studies on Back Discharge Mode and Streamer Preparation

- Present Status of Electrostatic Precipitator Technology

ISHIKAWAJIMA-HARIMA HEAVY INDUSTRIES

The visit with IHI provided an opportunity to develop an understanding of the viewpoint of an electrostatic precipitator manufacturer. This company relies heavily upon the developments of Professor Masuda of Tokyo University. One of their significant market items is the screen type collection electrode system mounted in the exit zone of a conventional electrostatic precipitator. **(See Appendix B.)**

Charging Part (PAC Part) (Pulse and Alternating Current Charger)

The PAC part consists of a discharging electrode, a facing electrode and a controlling electrode. A strong electric field is generated between the facing electrode and the controlling electrode by the power source.

The power source intermittently generates negative corona ions from the discharging electrode and drives these ions to the area between the facing electrode and the controlling electrode to charge the dusts in gas with a maximum charge.

The power source will regulate voltage in the controlling electrode and control the corona current.

Precipitating Part (ES Part) (Electrostatic Screen)

The ES part consists of guide electrode and precipitating electrode which are placed perpendicularly to the gas current. Those charged dusts at the PAC part are collected in the pocket of the precipitating electrode by a strong electrical field between electrodes and an electrohydrodynamic process which are generated by the power source.

Attendees: Ichiro Hattory, Chief Engineer
Mikoto Yabe
Yuichi Wada
Akira Shibuya

HITACHI LTD.

The visit with Hitachi Ltd. provided some insight into industrial research in Japan. The Research and Development Groups of Hitachi were represented by Kohji Yoshida, Hikaru Turii, Keizou Ootsuka, Hiroo Sakai, H. Yamada, Toshiaki Misaoa and Ryutaro Morita.

Several groups in Japan are investigating the influence of modifying the collection electrode spacing. Previous studies have indicated that there is a potential for improving the collection efficiency as a function of the required collection electrode area by increasing the plate-to-plate spacing while increasing the applied voltage in electrostatic precipitators. The more promising applications are those with reasonably low dust loadings such as roof monitors in metallurgical installations and similar areas.

The results of their plate spacing study led them to the conclusion that a wire-to-plate spacing of about 250 mm was an optimum spacing. They are continuing these studies. Their experiments show that migration velocity is proportional to plate spacing out to this distance. This, in their opinion, is somehow related to electric wind transport.

They also have some collection electrode systems with 1.8 cm diameter corona wires that are placed downstream of a conventional electrostatic precipitator that is probably related to Professor Masuda's work termed shoot (chute) baffles. This should provide high field strengths for collection. (Their opinion is that large wires decreases "electric wind" and enhances collection.) Dr. Masuda is also concerned with electric wind where we, the Soviets, and some Europeans tend to discount it at normal electrostatic precipitator current densities. They show some "schlieren" photos of electric wind effects and postulate that this aids in particle transport to plate by increased turbulence.

This device is termed the EP-SB for electrostatic precipitator-shoot baffle.

Configuration and Principle of EP-SB

The dusts at the entrance are charged electrically at the EP part where the large size particles are precipitated. The tiny particles are said to agglomerate to form large ones and will be carried to the SB part with electrical charges. In the SB part, the charged dusts are electrostatically precipitated by the high electric field which is charged to the SB part. These dusts will collide with shoot baffle and be precipitated mechanically.

This system is a one unit which is composed of EP part and SB part. The number of individual units required can be determined in accordance with necessary performance. Each unit can be installed in series with the gas flow. In case of using only the SB part in the already installed electrostatic precipitator for a purpose of improving efficiency, the exit-side exhaust pipe needs to be removed and the SB part will be placed in that space.

Effects of Special Shoot Baffle (Patent applied for)

A modified shoot baffle system has been designed for the purpose of reducing the pressure drop across the baffle system. A double layer of channels is arranged in the direction of the gas flow. The baffles have holes in the flat portion that allows some gas flow through the channel to increase the percentage of open area. The purpose of the two channels in the direction of gas flow is to reduce dust reentrainment.

They also discussed a light scattering instrument with a diluter that measures particles on a number per cubic meter basis similar to Royco except that it provides a readout in mass when calibrated. This instrument was claimed to give constant dilution ratios for particle sizes from 8.5 μm to about 100 μm.

Hitachi now markets both wet (intermittent spray) and dry type roof mounted electrostatic precipitators for use on roof monitors for metallurgical installations. The wet system uses natural draft for air flow. (Dry migration velocity ∿3.5/cm/sec-Wet 5 cm/sec).

Hitachi plans to introduce some high temperature electrostatic precipitators in Japan. The U.S. Team discussed the advantages and disadvantages of the high temperature precipitators. The American experience with hot-side electrostatic precipitator fly ash installations was of interest to the Hitachi group.

Hitachi has also conducted some laboratory experiments using a corona discharge to enhance the removal of SO_2 and NO_x in a wet electrostatic precipitator system. It is apparent that rather high levels of electric power consumption are required because the ozone concentration in the NO_x removal system was about 5%. At this time the electrical enhancement of SO_x and NO_x removal is only of academic interest because of the anticipated high power requirements. The small electrostatic precipitator operated at high current densities simulates the use of a high energy electron beam in promoting the conversion of SO_2 and NO_x to soluble compounds. In addition, the high current densities may produce additional gas turbulence to enhance gas liquid contact in the control device. Insufficient data are given to allow for an engineering analysis of the experiment.

List of papers that are included with translations in Appendix C

- High Temperature Electrostatic Precipitator for Coal-Fired Boiler (two papers summarized together)
- High Temperature Electrostatic Precipitators for Coal-Fired Boilers (pilot tests)
- Electric Field Distribution in Wide Plate Spacing Electrostatic Precipitator
- Elimination of SO_2 and NO in a Corona Discharge Field
- EP-SB Type Electrostatic Precipitators
- Measurement of Suspended Particulate
- Hitachi Dust Collection Equipment and Systems
- List of Hitachi Installations

SUMITOMO HEAVY INDUSTRIES (See Appendix D.)

Sumitomo Heavy Industries is a Japanese licensee of Joy-Western electrostatic precipitators. They are also involved in research related to varying the electrode spacing as a means to develop an optimized electrostatic precipitator design. They supply wide electrode spacing precipitators for roof monitors similar to the Hitachi unit discussed previously. They also have supplied an SO_3 conditioning system (H_2SO_4 evaporator) for the Isogo Power Station. The discussion group from Sumitomo included Mr. Noboru Watanabe, Shigeyuke Nōso and Masakazu Sakai.

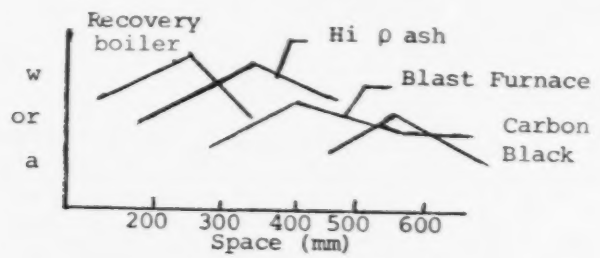
The Simitomo group utilizes a laboratory pilot scale electrostatic precipitator to assist in sizing new precipitators. The experiments make use of a redispersed dust.

The plate spacing experiments were conducted with a laboratory scale electrostatic precipitator that has the capability for varying the collection electrode spacing. The measurements consist of conducting mass loading experiments with a redispersed dust at representative mass loadings and temperatures. The precipitation rate parameter (effective migration velocity) is calculated from the Deutsch equation from the measured efficiency, volume flow rate, and collection electrode area. The experiments are conducted over a range of electrode spacings and the results are either plotted directly as the migration velocity vs plate spacing or as the ratio of the migration velocity as determined for a plate-to-plate spacing of 250 mm to that of the

experimental conditions. In either case, the form of the graphical presentation of the results are as shown below.

An example of the above, consider an experiment where two channels each with a collection electrode area of five meters square are used. In the first case, both channels are active. Assume that an efficiency of 90% results from an area of 10 meters square yielding a precipitation rate parameter (w) of 10 cm/sec. Next, the center collection electrode is removed and the corona electrodes are centered between the two remaining collection electrodes. Assume that this experiment also yields a collection efficiency of 90% with the same volume flow rate yielding a precipitator rate parameter of 20 cm/sec. Thus, the ratio of the precipitation rate parameter will be 2 when plotted.

The results of their studies of plate spacing are summarized below. They find that optimum spacing depends on resistivity, particle size and dust loading.



W is normalized to 250 mm for the comparison. Studies of varying plate spacings are continuing.

A description of the roof mounted electrostatic precipitator was provided.

NIPPON STEEL-KIMITSU WORKS

The research team visited the Kimitsu Steel Works of Nippon Steel with Professor Jumpei Ando. The chief of environmental control at the plant provided a briefing on the air pollution control equipment installed at this site. The plant proper was maintained in a very clean condition in all areas. The exterior areas were decorated with grass, shrubs and trees, in accordance with Japanese requirements.

The emissions from the stacks were well controlled. The sinter machine dust was controlled by a wide plate spacing electrostatic precipitator operating at about 200 kilovolts. Hoods over the blast furnace and convertor effectively captured the

emissions during the tap and oxygen blowing operations. In general, the air pollution control equipment seemed to be well designed and operated properly.

No technical literature was provided.

SHINWA TRADING AND ENGINEERING CO.

This company specializes in the control of emissions from the iron and steel industry. They are a Japanese licensee of American Air Filter, Louisville, KY. Their main areas of specialization are coke ovens--charging and pushing, general plant fugitive emissions and ferrosilicate electric arc furnaces. They have a monopoly on these installations in Japan. They have developed a traveling hood that connects into ductwork that allows individual coke batteries to be controlled during charging. They utilize wet scrubbers for this application (wet electrostatic precipitators also possible).

The charging door scrubber typically operates at a 99.9% efficiency with a pressure drop of 1800 mm W.C. with an outlet loading of about 40 mg/m^3 (normal).

They handle coke battery door leaks via a hooding arrangement. These emissions are usually controlled by the same device that controls the pushing. (A separate device could be used.)

The control device typically operates for 3 minutes with 6 minutes between for the coke battery pushing emission application.

The coke battery bag filter usually has bag life of 3 years. They operate at ~130°C with polyestor bag material. (Japan has some difficulty in attaining U.S. quality in glass bags.) Spark arresters are used in conjunction with this system.

The outlet emissions are limited by statute to about 200 mg/m^3 but the plant will typically control to 20 as a good neighbor.

They also install a fluid coupling to the fan system to conserve energy during the quiescent period. This fluid coupling allows operation from 30% to 100% fan capacity.

Shinwa does not now have any installations outside Japan but they have the design for one B.H.P.* (Australia Iron and Steel) in New Castle, Australia and have sold the technique to National Steel in Detroit.

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*Originally Broken Hill Proprietary.

The ferrosilica furnace baghouse is equipped with bags made of polyestor with stainless steel fibers woven into the material to eliminate electrostatic effects.

The Japanese bag filter technology uses reverse air cleaning.

The U.S. Team questioned them about other future markets. They stated that since steel is now down they have looked into auto foundries (some experience with Toyoto), cement industries, pharmacuetical and blast furnaces; are considering bag filters for power stations.

VISIT TO ISOGO POWER STATION

We visited the facilities of the Isogo Power Station of the Electric Power Development Company of Japan. This station is restricted in SO_x emissions to 60 ppm. The two units are equipped with electrostatic precipitators with sulfuric acid conditioning systems, followed by Chemico limestone scrubbers. Unit 1 has Lodge Cottrell and Unit 2 has Sumitomo Electrostatic precipitators.

The precipitators were designed to attain a 90% collection efficiency with gas conditioning. The units were initially equipped with gas conditioning because of the uncertainty in coal supply. They use coal from the Hokaida field with 15% ash, 0.6% sulfur and a heating value of 6500 kcal/kg. The stated outlet emissions from the electrostatic precipitators are 0.4 - 0.6 grams/normal cubic meters from Unit 2 and 0.3 - 0.4 grams/normal cubic meters of gas.

They have experienced some problems with SO_3 emissions when injecting SO_3. When injection exceeds about 20 ppm a brownish plume results. Probably the formation of a very fine mist that passes through the scrubbers. Normal injection rate is established at 11 ppm.

The Chemico scrubbers operate with a 50% slurry of ground limestone with a pressure drop of about 600 mm of water column. The outlet loadings from the scrubbers are each about 0.02 grams per normal cubic meter of gas. The gypsum formed contains significant quantities of fly ash and sells for ¥100 per ton (40¢). About 100 tons per day with 15% by weight water is processed.

The plant did a test burn of Montana coal about 3 years ago. The particulate control problems (resistivity) in the electrostatic precipitator could not be overcome by SO_3 injection! The plant personnel did not know which coal - but we suspect Coalstrip.

VISIT WITH PROFESSOR IINOYA - KYOTO UNIVERSITY

We met with Professor Iinoya on November 7, 1977. We asked Professor Iinoya to describe his current work, especially work on baghouse economics and electrostaticly augmented filters. Professor Iinoya gave us the following papers which he briefly discussed. (Papers are in Appendix H.)

- Dynamics of Naturally Cooled Hot Gas Duct
- Particle Size Classification by Deposition Angle in a Gas Centrifuge at Reduced Pressure
- Electrification of Gas-Solids Suspensions Flowing in Steel and Insulation-coated Pipes
- Experments on the Electrical Dislodging of a Dust Layer
- Comparison of Dust Cleaning Performance of Collapse and Mechanical Shaking Types of Fabric Filter
- On the Economically Optimum Design of Bag Filter
- Performance of a Micro-Cyclone
- International Seminar on Dust Collection
- Error in Measurement of Gas Flow Rate in Gas-Solids Two-phase Flow by Use of Horizontal Diffuser
- Dust Cleaning Dynamics in Reverse Collapse Type Bag Filter
- A Method of Measuring Pressure Drop Parameters for Multi-Compartment Bag Filter——Mechanical Shaking Type and Reverse Collapse Type——
- Performance of Fibrous Powder Bed Filter

Professor Iinoya is not continuing his work on economics or any of the other area covered by the above papers.

We toured his laboratories and observed work on mist elimination and filter pressure drop and efficiency. Work in these areas was not far enough along to be discussed.

Professor Iinoya showed us some dust feeders and a large impactor for ambient sampling.

Professor Iinoya plans to attend the particulate measurement meeting in Ashville, North Carolina in May and the symposium on particulate control in Denver, Colorado in July 1978.

UNIVERSITY OF OSAKA, PROFESSOR TETSUO YOSHIDA

This visit to Osaka University was a very interesting part of the evaluation of Japanese technology. This group was concentrating on the measurement of particulate characteristics. Discussions of papers, research reports, and laboratory demonstrations of the various measurement techniques were provided.

Dr. Yoshida gave an overall view of the research activities in his lab according to the outline below.

Dr. Kousaka then discussed the method of size analysis using gravitational settling with the ultramicroscope. The polydisperse aerosol is allowed to settle in a still chamber. By counting the number and size at a given distance down and knowing settling velocity the size distribution can be determined. Lower size limit about 0.2μ diameter.

Then a discussion of condensation growth was given. Three methods of super-saturation work was 1) mixing hot and cold streams, 2) steam injection, 3) adiabatic expansion. Results of this work agrees with Southern Research Institute's study of particle growth.

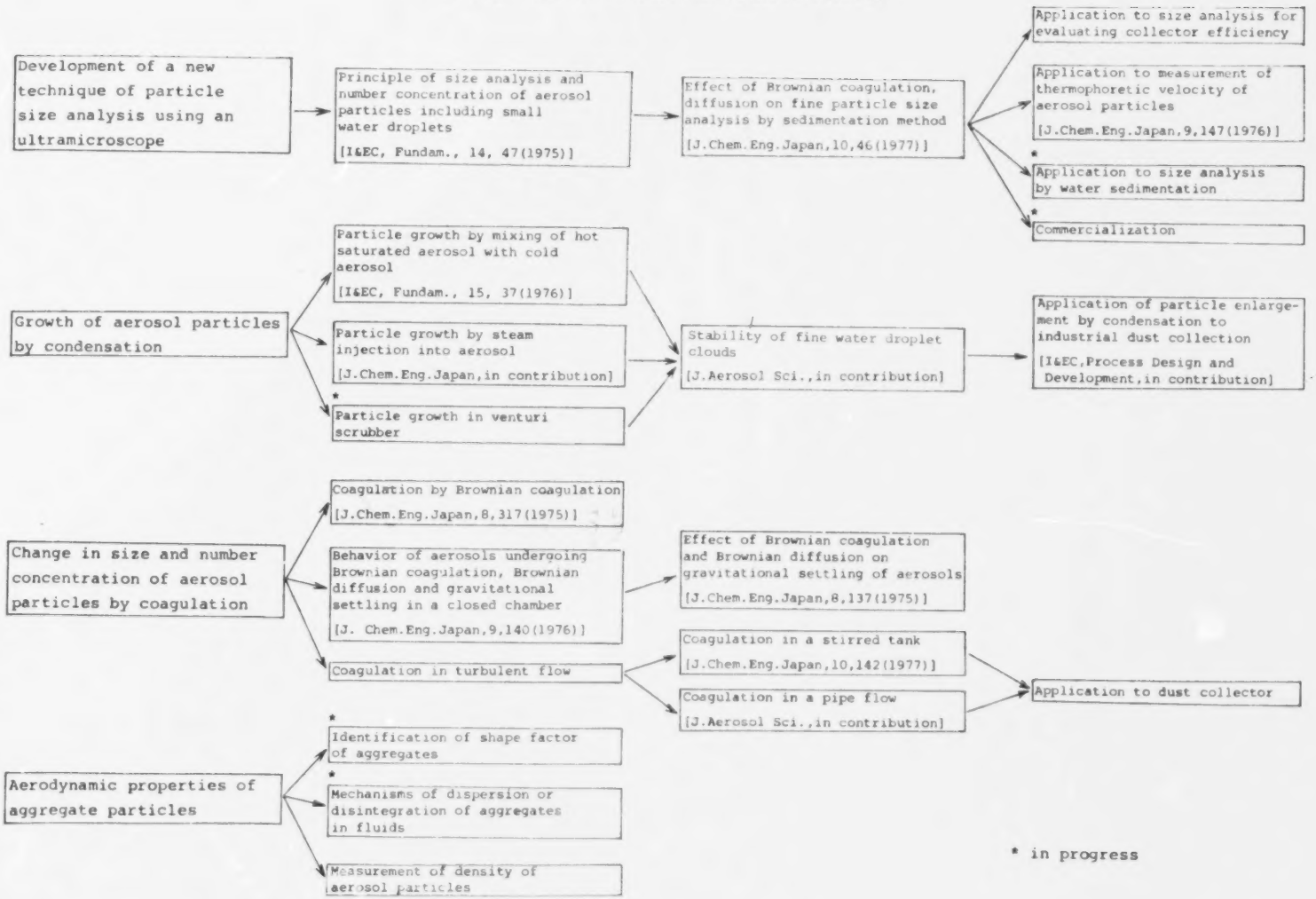
Les Sparks then summarized the work of Environmental Protection Agency in condensation growth and the sieve plate scrubber.

This group at University of Osaka assists in determining environmental impact of solid waste disposal, organic sludge, plastic waste, wood waste and hazardous waste. Japanese incinerators use electrostatic precipitators and scrubbers (SO_x control).

We were then shown laboratory demonstrations of:

- Growth by condensation (collection in scrubber)
- Aerosol size analysis (air sedimentation)
- Turbulent coagulation of tobacco smoke
- Thermophoresis effects
- Particle reentrainment ($CaCo_3$) at velocity from 20-100 M/sec

AEROSOL RESEARCH AT UNIV. OF OSAKA PREFECTURE


Development of a new technique of particle size analysis using an ultramicroscope
Principle of size analysis and number concentration of aerosol particles including small water droplets
[I&EC, Fundam., 14, 47(1975)]
Effect of Brownian coagulation, diffusion on fine particle size analysis by sedimentation method
[J.Chem.Eng.Japan,10,46(1977)]
Application to size analysis for evaluating collector efficiency
Application to measurement of thermophoretic velocity of aerosol particles
[J.Chem.Eng.Japan,9,147(1976)]
* Application to size analysis by water sedimentation
* Commercialization
Growth of aerosol particles by condensation
Particle growth by mixing of hot saturated aerosol with cold aerosol
[I&EC, Fundam., 15, 37(1976)]
Particle growth by steam injection into aerosol
[J.Chem.Eng.Japan,in contribution]
* Particle growth in venturi scrubber
Stability of fine water droplet clouds
[J.Aerosol Sci.,in contribution]
Application of particle enlargement by condensation to industrial dust collection
[I&EC,Process Design and Development,in contribution]
Change in size and number concentration of aerosol particles by coagulation
Coagulation by Brownian coagulation
[J.Chem.Eng.Japan,8,317(1975)]
Behavior of aerosols undergoing Brownian coagulation, Brownian diffusion and gravitational settling in a closed chamber
[J. Chem.Eng.Japan,9,140(1976)]
Effect of Brownian coagulation and Brownian diffusion on gravitational settling of aerosols
[J.Chem.Eng.Japan,8,137(1975)]
Coagulation in turbulent flow
Coagulation in a stirred tank
[J.Chem.Eng.Japan,10,142(1977)]
Coagulation in a pipe flow
[J.Aerosol Sci.,in contribution]
Application to dust collector
Aerodynamic properties of aggregate particles
* Identification of shape factor of aggregates
* Mechanisms of dispersion or disintegration of aggregates in fluids
Measurement of density of aerosol particles
* in progress

These experiments made use of the ultramicroscope. This seems to be a most capable group.

The following publications are given in Appendix I:

- Growth of Aerosol Particles by Condensation
- Stability of Fine Water Droplet Clouds
- Behavior of Aerosols Undergoing Brownian Coagulation, Brownian Diffusion and Gravitational Settling in a Closed Chamber
- A New Technique of Particle Size Analysis of Aerosols and Fine Powders Using an Ultramicroscope
- Turbulent Coagulation of Aerosols in a Pipe Flow
- Effects of Brownian Coagulation and Brownian Diffusion on Fine Particle Size Analysis by Sedimentation Method
- Constant Pressure Filtration of Power-Law Non-Newtonian Fluids
- Experimental Study of Thermophoresis of Aerosol Particles
- Turbulent Coagulation of Aerosols in a Stirred Tank
- The Effect of Neighboring Fibers on the Single Fiber Inertia-Interception Efficiency of Aerosols
- Pressure Drop and Collection Efficiency of an Irrigated Bag Filter
- Growth of Aerosol Particles by Steam Injection
- Effect of Brownian Coagulation and Brownian Diffusion on Gravitational Settling of Polydisperse Aerosols
- Change in Particle Size Distributions of Polydisperse Aerosols Undergoing Brownian Coagulation
- Application of Particle Enlargement by Condensation to Industrial Dust Collection

MITSUBISHI HEAVY INDUSTRIES

We visited the Takasago Research Institute of Mitsubishi. Messrs. Matsui, Saito, Toshiro and Dr. Matsumoto were present.

Mr. Saito reviewed the work of the three Mitsubishi research laboratories—Takasago, Nagasaki and Heroshima.

The Mitsubishi electrostatic precipitator research is conducted at this laboratory. Mitsubishi does not study specifically the collection of fine particles but rather studies improving the overall collection efficiency of the electrosatatic precipitator.

We were given sales brochures and a paper on Dust Collection Techniques. (See Appendix J.)

The Mitsubishi Heavy Industries group is a cooperative licensee of the Lurgi group in Germany. They study the electrical and aerodynamic factors related to particulate collection with an electrostatic precipitator including the following items:

- Effect of varying plate spacing
- High resistivity effects
- Space charge suppression
- Corona electrode configuration
- Temperatures
- Gas flow distribution
- Wet and dry collection

Their major high resistivity problem is with Sinter machine dust.

Their studies of plate spacing show that so long as a given current density is maintained, increasing plate spacing with a constant plate area increases efficiency. This applies to coarse dust, light loadings and high temperatures.

With respect to high resistivity, they have developed a measurement cell that allows temperature and pressure to be varied. They determine the sparkover characteristics with clean gas and with a dust layer deposit in a wire-pipe electrostatic precipitator. From this they determine the temperature where the spark charcteristics are independent of the presence or absence of the layer. They term this point the back corona vanishing point. We believe that this term is incorrect, but it does in fact define the temperature at which the influence of the dust layer is insignificant and as such is a valuable experiment. This will yield results similar to those with the electrostatic precipitator field mobility analyzer developed at Southern Research Institute. (The electrostatic precipitator system operates in situ at a given temperature. This Japanese device has been used to study the fly ash from Hayden, Colorado.)

They have tried a number of methods to reduce the effect of high resistivity of Sinter machine dust—all failed. Large spacing, water injection, ammonia injection and mixing carbon dust with gas stream. The carbon was essentially all collected in the inlet field. This helped that field only. (They may have injected only large particles because redispersion is difficult.) They are now evaluating different corona electrodes.

The space charge suppression can be handled over a limited range by the use of high current density corona electrodes. The installation of corona electrodes with a small radius of curvature leads to a corona inception voltage less than that for normal electrodes. Thus, a higher current density exists for the same operating voltage for the smaller diameter wires. Therefore, since the sparkover voltage will be approximately the same for the two-wire diameters, the space charge suppression problem will be alleviated somewhat.

They also design installations for no flow-power off rapping. Four chambers are installed with dampers. One-fourth is shut off and rapped. This improves performance for Sinter machine operation.

They also think "electric wind" erosion is significant.

The laboratory illustrated the effect of back corona by photographing particle trajectories (8-10μ particles). A strobe light illuminates the particles. Trajectory is to the plate w/o back corona but approaches and reverses with back corona.

The design for new installations is generally based on pilot studies. They scale up with an experience factor. The pilot and full-scale V-I curves are in general identical except the sparkover voltage is greater in pilot.

Pilot	Full Scale
V-I	V-I
Vspk	V's = Vspk
W	W' = BW (B is a proprietary parameter)

We toured the laboratory to view their equipment. The lab was well equipped.

SECTION V

LITERATURE REVIEW

This section provides summaries of the technical literature supplied at each meeting that relate to particulate control. Complete copies of the papers are included in the respective Appendices. The order for the summaries coincide with the lists provided in Section IV.

UNIVERSITY OF TOKYO

This group of papers provides information about the research activities under the direction of Professor Senichi Masuda. Complete copies of the papers are reproduced in Appendix A.

Initiation Condition and Mode of Back Discharge, S. Masuda and A. Mizuno

This paper provides a detailed discussion of the development of back corona in layers of high resistivity material. The discussion includes the development of the theory, experimental investigations utilizing tissue paper and millimeter thick layers of glass and mica, and development of the factors that lead to the development of back corona. In this research, the thin glass and mica layers had pinholes through the material such that tangential electric fields could be established by utilizing two layers with the pinholes displaced.

The breakdown characteristics are classified into three modes—space streamer, surface streamer and mixed streamer. The first and third modes occur when the electric field adjacent to the layer exceeds about 5 kv/cm with ions formed in the inter-electrode space. The second mode develops with field strengths less than 5 kv/cm with ions only generated adjacent to the layer surface.

This paper provides a good background into the study of back corona. Even though the experiments utilized a simulated dust layer, the results in general apply to electrostatically collected dust layers.

Back Discharge Phenomena in Bias Controlled Pulse Charging System, S. Masuda, I. Doi, I. Hattori and A. Shibuya

The use of pulsed electrical power supplies has been considered as a means to reduce the development of back corona in electrostatic precipitators collecting high resistivity fly ash by several investigators. Dr. White describes experiments with pulse power supplies in his book, "Industrial Electrostatic Precipitation". The Environmental Protection Agency sponsored some research with Belco Engineering in the early 1970's. In general, the studies and experiments failed to provide the degree of improvement expected. This failure to improve was related to the filtering action of the collected high resistivity dust layer and the corona-collection electrode system.

This paper describes experiments with a laboratory and subsequently a pilot scale electrostatic precipitator that involves the addition of a third electrode located near the corona wire. This three-electrode system provides a high value of D.C. field adjacent to the collection electrode by applying a fixed voltage with very little or no corona current to serve as the collecting field. The corona current is supplied by applying pulses of voltage to the corona electrode that provides current pulses of about one hundred microseconds duration with a variable repetition rate. This provides a free ion density in the interelectrode space that is sufficient to charge the particles but low enough, on the average, to avoid the formation of back corona. The collection field is provided by a near-passive electrode system while the charging current is supplied intermittently. This arrangement simulates a distributed two-stage electrostatic precipitator.

This technique represents a new approach to the solution of the high resistivity problem by electrical means. This represents a significant improvement in the use of pulse energization for electrostatic precipitators.

Light Measurement of Back Discharge, S. Masuda and A. Mizuno

This paper describes the results of a study of the light that is associated with the formation of back corona. Two distinct light forms are categorized. The primary light wave forms in the dust layer and propagates to the corona electrode. The secondary wave appears coincident with the arrival of the primary wave and travels along the dust layer surface. At reduced pressures ($p<1/2$ atmos) free electron transport contributes to the formation of the gas discharge. At atmospheric pressure, negative ions are responsible. Repeated streamer discharges cause a "heated" channel that will develop into electrical flashover when this leader arrives at the discharge electrode.

Initiation Condition and Mode of Back Discharge Extremely High Resistivity Powders, S. Masuda, A. Mizuno and K. Akutsu

This laboratory study of the formation of back corona provides significant fundamental information of the characteristics of reverse ionization. The study clearly shows the dependence on dust layer thickness, indicating that the electrical space charge within the dust layer adds to the Ohm's Law field to cause the development of a high electric field adjacent to the grounded electrodes. The most significant point of this research is the indication that a dust layer of high resistivity material will build up until a limiting value of electric field is reached adjacent to the grounded electrode. At this point, back corona will develop in localized regions reducing the particulate buildup severely.

Utility Limit and Mode of Back Discharge in Bias Controlled Pulse Charging System, S. Masuda, I. Doi, I. Hattori, and A. Shibuya

This paper describes the use of a pulsed charging system that operates with a three-electrode geometry in the charging section. The pulse charging pulse is superimposed on a D.C. exitation which, in conjuction with the third electrode, reduces the development of back corona. This pulse system differs from attempts to utilize pulsed power supplies in the United States in that the pulse charging is applied in series with a D.C. Bias, rather than using a pulse supply alone. Sharp rise and fall edges on the pulse voltage supplied to the electrical assembly are used. This is also in contrast with attempts by U.S. researches who could attain sharp rise times but the decay time of the voltage was related to the electrical time constant of the electrode system and dust layer combination.

The Analysis of Electric Wind in Electrostatic Precipitator by Laser Doppler Velocimeter, S. Masuda, K. Akutsu, and K. Aihara

This paper describes experiments conducted with a laboratory apparatus to investigate the phenomena of the electric wind from the corona electrode and from back ionization. It is to be noted that the conditions for this experiment deviates significantly from those conditions existing in commercial electrostatic precipitators in that the current densities are expected to be somewhat greater than that usually encountered and the glass plate represents an unrealistically high resistivity. The point-to-plane system with close spacing provides for very high current densities and no requirement for a flow of return air such as is present in operating units. Therefore, the conclusion from this paper relates to the experimental conditions existing in the laboratory apparatus.

In this experiment, electric wind velocities were on the order of a few meters per second with a current of 5 microamperes. The actual plate area used for the experiment was not stated but a current density of 640/μA/m^2 was stated. This suggests a plate area of about 100 cm^2 in the measurement region. However, for a point-to-plane experiment with 5 cm between the point and plane, a significant variation in current as a function of distance along the plane is expected. Thus it is difficult to determine the current density at the plate.

Fundamental Analysis of Electron Beam Gas Elimination, S. Masuda, K. Akutsu and M. Harano

This paper discusses the removal of NO and SO_x in the presence of high-energy electrons. A beam of one to two MeV electrons is injected into the gas stream. The high-energy electron oxidizes the NO to enhance the removal of this gas. The removal of SO_2 is improved by the injection of ammonia into the reaction space. The experimental results show that the removal efficiency for the gases is related to the electric power input into the reaction space.

Motion of Microcharge Particle With Electrohydrodynamic Field, S. Masuda and Y. Matsumoto

This paper provides a theoretical analysis of the shoot (chute) baffle downstream collector that is one of the major modifications to electrostatic precipitators that Dr. Masuda is investigating. In addition to the theoretical analysis, experiments utilizing lycopodium particles and photographs of their trajectories are included. This device is a modified two-stage precipitator. The paper is a good background paper related to the behavior of charged particles in an electrostatic field.

A Preliminary Study of Reentrainment in an Electrostatic Precipitator, J.D. Bassett, K. Akutsu and S. Masuda, Journal of Electrostatics, pp 311-325 (1977)

This paper describes the results of a study to define the conditions under which direct reentrainment occurs from an electrostatically deposited dust layer. The study includes photographs of particle trajectories with and without the existence of back corona. Distinct differences in the trajactories were noted with back corona.

Recent Progress in Electrostatic Precipitators, S. Masuda

This paper is a survey of the research programs that were active in the 1975 period. A general discussion of Electrostatic Precipitator Theory is used as an introduction. The research programs at the University of Tokyo are reviewed in detail.

Flashover Measurements of Back Discharge, S. Masuda and A. Mizuno

This paper describes conclusions from measurements from a gas discharge with a current flow through a high resistivity layer at varying conditions of temperature and pressure. Two modes of electrical breakdown were identified: streamer or steady glow. The development of each mode is dependent upon the gas mean free path, dust layer thickness and layer resistivity. The streamer mode includes a steady D.C. component of current with superimposed trichel pulses, while the glow mode is characterized by a steady D.C. current. The mechanism of breakdown begins with a spark breakdown through the dust layer leading to an ionized channel. Initially the location of these channels moves randomly over the surface of the layer. As the voltage (and current density) is increased the localized breakdown occurs repetitively in one location, from which a streamer develops. The resistivity of the dust layer strongly influences the initial point where electrical breakdown occurs but after breakdown, the layer resistivity becomes inconsequential.

Basic Studies on Back Discharge Mode and Streamer Propagation, S. Masuda and A. Mizuno

This paper, presented at the fourth international clean-air congress, represents a continuation and summary of the research reported in the first paper in this section, "Initiative Conditions and Mode of Back Discharge". The three modes of layer breakdown are described in detail and graphically illustrated. The experiments are with a point-to-plane corona device with a high resistivity layer simulated. A graph with axes of average electric field and current density is divided into regions that yield surface streamers, space streamers and mixed streamers. Waveforms of the light emitted for the various conditions are shown. Studies of the influence of ionic mean free path on flashover voltage are reported.

Present Status of Electrostatic Precipitator Technology, S. Masuda

This paper was presented at the Electrochemical Colloqium of the Technical University of Munich in 1977. It is closely related to the previous paper, "Recent Progress in Electrostatic Precipitation". A general discussion of the various aspects of electrostatic precipitation is included. The specific topics covered were particle charging mechanisms, migration of charged particles, gas turbulence, jet streams, corona wind, back corona and particle reentrainment. Also, experiments with variable collection electrode spacing are described. The influence of corona wind is stressed rather heavily. Professor Masuda attributes several factors to corona wind that other investigators tend to disregard. This probably bears further investigation.

ISHIKAWAJIMA-HARIMA HEAVY INDUSTRIES NEW PRECIPITATION TECHNIQUES—PAC-ES

This technical information bulletin describes two developments from Professor Masuda; pulse and alternating current charger (PAC) and the electrostatic screen (ES) collecting device. The theoretical descriptions of the devices are covered in the literature from Professor Masuda at Tokyo University (Part 1 of Section V). The practical factors and some general discussions are included in the bulletin.

HITACHI LTD. (Papers in Appendix C.)

High Temperature Electrostatic Precipitator for Coal-Fired Boiler, H. Imanishi, Y. Oataki, K. Ootsuka and K. Watanabe

This paper is a general discussion paper summarizing the state of technology for electrostatic precipitators installed on the hot gas side of air preheaters in coal-fired electric utility boilers. The paper also includes a short summary of electrostatic precipitator technology in general. The discussion paper is considered to be significant because there is limited Japanese experience with the so-called hot side electrostatic precipitators. This is considered to be a good summary paper.

A second paper of the same name summarizes the results of a pilot scale test at the Ebetse Generating Station of Hokkaido Electric Power Company. The conclusion was that the performance of the high temperature pilot electrostatic precipitator performed acceptably. This paper was coauthored by Mr. Y. Oataki of Hokkaido Electric.

Electric Field Distribution in Wide Plate Spacing Electrostatic Precipitator, T. Misaka, S. Matsubara and K. Fujibayaski

This short paper reports the results of a laboratory investigation of the electric field distribution within the interelectrode space of a wire and plate electrostatic precipitator. The electric field was mapped for electrode spacing of 250,500 and 750 mm. The method utilized was a conducting sphere dropped through the interelectrode space into a Faraday cage.

Elimination of SO_2 and NO in a Corona Discharge Field, K. Ootsuka, T. Yukitake and M. Shimoda

This paper discusses the results of an experiment to utilize the ozone formed in a high current density corona to oxidize sulfur and nitrogen oxides to water soluble forms. The process requires a considerable amount of electrical energy, since the ozone concentration in the experimental apparatus was considerably higher than in conventional electrostatic precipitators ($\sim$5%).

Hitachi EP-SB Type Electrostatic Precipitator

This discussion provides a short summary of a high electric field, low current density electrostatic precipitator that is installed downstream from a conventional electrostatic precipitator. Sketches and examples of the specifications applicable to a cement plant are given.

Measurement of Suspended Particulates, K. Ootsuka, S. Tsuji and Y. Ari'awa

This paper discusses the development of an optical measurement system used in conjunction with a sample dilution system to determine the concentration of particles suspended in a gas stream. A sample of the gas stream is extracted, diluted with clean air and viewed with an optical particle counter. The authors claim that the readout can be in mass loading as well as number density when properly calibrated.

There were no summaries provided for Hitachi Dust Collection Equipment and Systems and List of Hitachi Installations.

SUMITOMO INDUSTRIES (Paper in Appendix D.)

The Sumitomo group provided a publication describing their capabilities in providing roof mounted electrostatic precipitators for low mass loading applications. This document includes comparison with alternative particulate control techniques. The roof mounted electrostatic precipitators utilize wide plate spacing and high voltage as a means for reducing the weight of the control device.

There was no literature to review for

Nippon Steel-Kimitsu Works
Shimwa Trading and Engineering Co.
Visit to Isogo Station

KYOTO UNIVERSITY

The research program at Kyoto University is related to the fundamental behavior of dispersion dusts. The literature review of the papers (see Appendix H) follows.

Dynamics of Naturally Cooled Hot Gas Duct, K. Hotta, N. Yamamuro and K. Iinoya

This paper describes the development of a mathematical model of the transient thermal behavior of a gas duct that is cooled by exposure to ambient conditions. The study is applicable to

ductwork leading from a process to a fabric filter installation.

Particle Size Classification by Deposition Angle in a Gas Centrifuge at Reduced Pressure, Z. Tanaka, H. Takai, N. Okada and K. Iinoya

This paper discusses the results of a study of the operation of a Bahco type of centrifugal classifier operated at reduced pressures. The reduction in pressure causes an increase in the average molecular spacing which causes the Cunningham correction factor to Stokes Law to become effective at larger particle diameters. Both theoretical and experimental results are presented.

Electrification of Gas-Solid Suspensions Flowing in Steel and Insulating-Coated Pipes, H. Masuda, T. Komatusu, N. Mitsui and K. Iinoya

This paper discusses the results of a laboratory study of the contact charging of dust particles flowing in both conducting and nonconducting pipes. This tribo-electric charging study is of interest as a potential means for determining mass loading in a gas stream. This principal is utilized in an instrument, the Konitest meter, developed in West Germany. This phenomenon is also responsible for electrical sparking in some dust laden gas streams that may lead to ignition and possibly explosion, in some instances.

Experiments on the Electrical Dislodging of a Dust Layer, K. Makino, K. Iinoya, M. Shibamoto, S. Toyama and M. Ikazaki

This study was aimed at defining electrical means to dislodge both insulating and conducting powders from various types of transport media. A moving electric field was generated by applying phased A.C. power to an electrode array. At this time, this technique does not seem to apply to electrostatic particulate collection.

Comparison of Dust Cleaning Performance of Collapse and Mechanical Shaking Types of Fabric Filter, K. Iinoya, K. Makino, Y. Mori, J. Okutani and H. Kawabe

The cleaning characteristics of the above fabric filter collectors are studied. Optimal cleaning durations and cycles are determined experimentally. In general, shorter cleaning durations are found to be advantageous.

On the Economically Optimal Design of Bag Filter, K. Iinoya, K. Makino, and N. Tanaka

This paper develops a method with equations to guide the designer of a fabric filter system in determining the economically optimum unit for a given installation. Both theoretical and practical considerations are included. Assumptions for bag life related to the cleaning cycle are given.

Performance of a Micro-Cyclone, K. Iinoya and A. Nakai

The performance of a micro-cyclone, collection efficiency vs pressure drop, was experimentally determined using monodisperse aerosols. The pressure drop was proportional tc the square of the inlet velocity. The collection efficiency can be correlated with an inertia par meter with a modification factor for particle size.

International Seminar on Dust Collection, K. Iinoya

This paper is a summary of a meeting to discuss the general properties of dust collection. Discussions were presented by F. Löffler of Germany, E. C. Potter of Austrailia, M. First of the United States, and W. Stöber of Germany. This summary is reproduced in the Appendix.

Error in Measurement of Gas Flow Rate in Gas-Solids Two-Phase Flow by Use of a Horizontal Diffuser, H. Masuda, Y. Ito, and K. Iinoya

This paper discusses errors in measurements of flow in a gas-solids gas stream. The experimental powders used are unusually large but the analytical procedure is useful.

Dust Cleaning Dynamics in Reverse Collapse Type Bag Filter, K. Makino, Y. Mori, N. Takado, and K. Iinoya

This study provides information about the influence of the cleaning cycle on the operation of the fabric filter. This particular study was concerned with a collapse type of cleaning. Time constant for recovery were developed.

A Method of Measuring Pressure Drop Parameters for Multi-Compartment Bag Filter—Mechanical Shaking Type and Reverse Collapse Type—K. Iinoya, K. Makino, K. Ueshima, M. Lin and Y. Mori

This paper discusses the development of a means for evaluating the performance of bag filters. Typcially, one or two years is required for a field installation to develop an operating history. This study discusses the development of a pressure drop-collection efficiency history for a given installation to be applied to estimating the performance of new installation.

Performance of Fibrous Powder Bed Filter, K. Iinoya, K. Makino, T. Imamura, and H. Okura

This paper discusses the results of a study of the collection characteristics of a packed bed filter. The collection efficiency and pressure drop of the device was presented. Empirical performance equations were developed.

UNIVERSITY OF OSAKA PREFECTURE

The research program at the University of Osaka is concentrated on the development of measurement techniques and in the fundamental behavior of particles suspended in a gas stream. This group of papers provides a good introduction to the physics of fine particulates.

Papers have been prepared that consider the combined influence of growth by condensation, Brownian diffusion and coagulation, gravitational settling and thermophoretic movements. The group has perfected the use of an ultramicroscope connected to a television optical system to study the various phenomena. The following summaries describe these papers, reprinted in Appendix I.

Growth of Aerosol Particles by Condensation, T. Yoshida, Y. Kousaka, and K. Okuyama

This paper addresses the theoretical and experimental aspects of condensation growth. This principle is used in instruments to determine number concentrations of fine particles. The experimental determinations were made with the ultramicroscope. Supersaturated gas streams were found to provide for the growth on the particles active as condensation nuclei.

Stability of Fine Water Droplet Clouds, Y. Kousaka, K. Okuyama, K. Sumi and T. Yoshida

This experimental study provided information important to the use of condensation growth of fine particles. The results of this study indicates that micron size droplets will evaporate even in the presence of saturated air. Thus, very few fog particles will be in a state of equilibrium. Thus, care should be exercised in the use of this phenomenon in designing size sensitive measurements.

Behavior of Aerosols Undergoing Browning Coagulation, Brownian Diffusion and Gravitational Settling in a Closed Chamber, K. Ikuyama, Y. Kousaka and T. Yoshida

This theoretical and experimental paper addresses the fundamental behavior of aerosols in a closed chamber. The mechanisms lead to growth by collisions, wall losses by diffusion and settling on the bottom surface. This fundamental study leads to the development of instrumentation for real time determination of a particle size distribution in a particulate laden gas stream.

A New Technique of Particle Size Analysis of Aerosols and Fine Powders Using an Ultramicroscope, T. Yoshida, Y. Kousaka and K. Ikuyama

This paper describes an instrument for sizing particles while they are suspended in a stationary gas stream. The

ultramicroscope is focused at some distance down into a view chamber. The instrument is used to view the results of gravitational settling of particles within the view volume. Near real time results are available. Data for stearic acid, tobacco smoke, fog and iron oxide particle size distribution are provided.

Turbulent Coagulation of Aerosols in a Pipe Flow, K. Okuyama, Y. Kousaka and T. Yoshida

Two factors lead to collisions between particles suspended in a turbulent gas stream: velocity differences because of spatial inhomogeneities in the flow pattern and the differential inertion of different particle sizes. Both mechanisms are active for the flow in a pipe. These factors were evaluated using the ultramicroscopes.

Effects of Brownian Coagulation and Brownian Diffusion on Fine Particle Size Analysis by Sedimentation Method, K. Okuyama, Y. Kousaka, T. Miyazak, and T. Yoshida

This paper discusses the effects of diffusion and coagulation on the Stokes-Cunningham conditions. These factors influence the accuracy of particle size determinations by sedimentation techniques. Theoretical analyses and some experimental varifications are included.

Experimental Study of Thermophoresis of Aerosol Particles, Y. Kousaka, K. Okuyama, S. Nishio, and T. Yoshida

The ultramicroscope described above can be used in conjunction with a special thermally controlled cell to study the thermophoretic transport of particles. The results of experiments from a variety of particulates are compared with the theoretically predicted behavior. Good agreement is indicated in these comparisons.

Turbulent Coagulation of Aerosols in a Stirred Tank, K. Okuyama, Y. Kousaka, Y. Kida and T. Yoshida

The ultramicroscope serves as a useful tool for evaluating the many physical phenomena related to fine particles suspended in a gas stream. This experiment evaluates the turbulent coagulation particles within the view volume of the instrument. The turbulence is provided by utilizing a stirred tank. Tobacco smoke was the principal material used in the experiment. The deviation in results associated with wall depositors were treated mathematically.

Presssure Drop and Collection Efficiency of an Irrigated Bag Filter, T. Yoshida, Y. Kousak, S. Inake and S. Nakai

This paper discusses the results of an investigation to develop a means for utilizing fabric filters on high temperature applications. The surface of the fabric filter is flooded with a water film. In addition to thermally protecting the fabric and removing the material that would form the cake in a conventional bag filter, the liquid film provides two collection mechanisms that differ from normal fabric filter collection mechanism: collection by an orifice in an infinite plate and collection by the shutter action of an orifice. The liquid flowing over the fabric surface forms a continuous sheet. Pressure differentials across the fabric leads to a break in the surface film. The pressure drop as a function of operating time is essentially constant because of the action of the liquid film, in contrast to that in a dry fabric filter when pressure drop and collection efficiency increase with time of operation.

Growth of Aerosol Particles by Steam Injection, T. Yoshida, Y. Kousaka, K. Okuyama and F. Nomyra

This paper discusses the results of growing particles by the condensation of water vapor on the particles. The fine particles act as condensation nuclei in a supersaturated gas steam. The results of this experiment are consistent with a similar study in the United States that led to the development of a condensation nuclei counter that is currently used for particle number density determination. Both theory and experimental information are included.

Effect of Brownian Coagulation and Brownian Diffusion on Gravitational Settling of Polydisperse Aerosols, T. Yoshida, Y. Kousaka, K. Okuyama and S. Nishio

This paper includes the development of equations based on the theoretical behavior of a polydisperse aerosol as well as an experimental study using the ultramicroscope. Stearic acid and tobacco smoke aerosols were used in the study. The number densities for the studies ranged from 10^6 to 10^8 particles per cubic centimeter.

Change in Particle Size Distributions of Polydisperse Aerosols Undergoing Brownian Coagulation, T. Yoshida, K. Okuyama, Y. Kousaka and Y. Kida

This paper reports the result of a study to evaluate the influence of a single factor on the particle size distribution—Brownian coagulations. A very high number density polydisperse aerosol was confined in a chamber. The high number density assured that coagulation was the primary mechanism active within

the system. The ultramicroscope was used to study the phenomena and theoretical confirming equations were provided.

Application of Particle Enlargement by Condensation to Industrial Dust Collection, T. Yoshida, Y. Kousaka, K. Okuyama and F. Nomyra

Introduction--

Industrial application of the principles of growth of aerosol particles by condensation was made in this paper. Condensation of water vapor on aerosol particles, not consisting of soluble substances, occurs when a certain degree of supersaturation is produced around the particles. Supersaturation is usually produced by one of two methods. In one method, hot saturated air is mixed with cold air, while in the second method steam is injected into the air. Methods of developing these processes economically were discussed in this paper. The fundamental considerations of these two processes were discussed by the authors in an earlier paper.

Discussion--

Four processes for producing particle growth by condensation were discussed. The first process named "A" applies for high temperature and high humidity exhaust gas. In this process, the humidified gas is divided into two parts. One is contacted with cooling water and then mixed with the other in a mixing chamber. In a similar process called "A'", one part of the gas is humidified and heated by hot water to form high temperature saturated air while the other part is humidified by cool water to form low temperature saturated air. The two parts are then mixed. For low temperature exhaust gas, the steam injection method is effective, but it requires saturated steam. This process is labeled "B". At intermediate temperatures of the exhaust gas the process is called "B'".

In the experiments described in this paper, the temperature of the gas was several hundred degrees celsius for process "A" and about 200 degrees for process "B'". Tobacco smoke with volume mean diameter of 0.85 microns and dust particles with volume mean diameter of 0.1 microns were used as condensation nuclei. The total gas flow rate was 180 l/min.

MITSUBISHI HEAVY INDUSTRIES, LTD.

The Latest Dust Collecting Technique, Y. Saito, K Tashiro, S. Komura, N. Tachibana, K. Matsui and K. Yada

This paper presents a qualitative summary of the Mitsubishi philosophy of electrostatic precipitator design and a summary of precipitator technology. The results of several laboratory investigations are also mentioned. This summary includes discussions of the significance of reentrainment, high resistivity,

high dust loading of fine particulates and the influence of sulfur and nitrogen oxide removal. (See Appendix J.)

SECTION VI

TECHNOLOGY ASSESSMENT

The Japanese research activities related to electrostatic precipitation and particulate measurement techniques are judged to be on a par with, and in some instances, surpass those of the other major countries in the world. The specific areas where the electrostatic precipitation technology seemed to lead include the following:

Fundamental studies of back corona formation,

Pulse electrical energization with a three-electrode geometry, and

Special electrode configuration to provide high collection electric fields.

Their experiments with variable collection electrode spacings are also very timely. Optimizing the electrode spacing to match the conditions of mass loading, particle size distribution and particulate resistivity can lead to a reduction in the weight of a given installation while maintaining the necessary particulate collection efficiency.

Another area of significant research is that related to particulate measurement techniques. The development of the ultramicroscope at the University of Osaka and the optical sizing instrument with a wide particle size range diluter are two of the more significant developments in this area.

The efforts of Professor Masuda at the University of Tokyo represents a most significant area of research related to electrostatic precipitation. His studies of the factors leading to the formation of back corona represents one of the more fundamental attempts to investigate this phenomenon. His work with a simulated dust layer has allowed the back corona condition to be classified into three regions dependent upon the value of the electric field adjacent to the collected dust layer—space streamer, surface streamer, and mixed streamer modes.

The next significant contribution to electrostatic precipitator technology is the study of pulse energization for high resistivity dust applications. Many investigators have evaluated

the use of pulsed power supplies. The basis for considering the use of short duration pulses was that since the dust layer on the collection electrode acted as an resistance-capacitance filter, the average electric field in the dust layer would be proportional to the average current rather than the peak current. Unfortunately, the average electric field adjacent to the dust layer was also reduced and the collection efficiency for the device was less than hoped for.

Professor Masuda has circumvented this problem by utilizing a three-electrode system. The collection field is established by applying a high voltage between passive electrodes that provide either little or no corona current. The corona electrode situated in the vicinity of the third electrode is supplied with short duration pulses (20 microseconds), at a controllable repetition rate, to provide the current necessary for particle charging. Thus, the system maintains an acceptable charging current and a high electric field for collection.

The three-electrode charging system naturally led into studies of high electric field-low current density collectors. The charged particles exiting the pulse charging section could be effectively collected in a high electric field region. This high field could be supplied by an electrode system consisting of strategically located channels with low or negligible corona current. These channel electrodes were called shoot (chute?) baffles.

Another significant area of technology development is in the studies of variations in the corona to collection electrode spacing. Historically, the electrode spacing was dictated by the availability of high voltage power supplies. Even after higher voltage power supplies were developed, the standard nine- to twelve-inch plate-to-plate spacings were retained. However, there is no reason to believe that nine- to twelve-inch spacings are the optimum for every condition of mass loading, particle size distribution, gas density and particulate resistivity. Therefore, this research into plate spacing is considered to be timely.

Significant research into the measurement of particulate characteristics is currently active in Japan. Professor Yoshida and associates at the University of Osaka have developed an instrument called an ultramicroscope that is extremely useful for studying particulate characteristics. The ultramicroscope, used in conjunction with a television display system, is focused some distance into a particulate laden gas stream. The behavior of individual particles within an ensemble of particles can be evaluated. Many studies involving Brownian diffusion and coagulation, thermophoresis gravitational settling and growth by condensation are conducted with this instrument.

One development by the industrial concern of Hitachi is also noteworthy. They have developed an optical particle counter that is used in conjunction with a proprietary dilution system that is stated to provide constant dilution ratios for particles up to about 100 μm in diameter. This instrument can read out in number per unit volume or mass per unit volume when correctly calibrated.

In general, the state of electrostatic precipitator technology and particle characteristic measurement technology in Japan is on a par with the United States. In the areas of pulse energization and fundamental studies of back corona, their technology perhaps surpasses that in the United States. The Japanese investigators welcomed discussion of the U.S. research efforts equally as we did theirs. A continuation of this interchange of information is contemplated.

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